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HUMAN FACTORS ANALYSIS OF DRIVER BEHAVIOR BY EXPERIMENTAL SYSTEMS METHODS*

KARL U. SMITH
Behavioral Cybernetics Laboratory, University of Wisconsin

HENRY S. R. KAO
Highway Safety Research Institute, University of Michigan

and

RICHARD KAPLAN
Behavioral Cybernetics Laboratory, University of Wisconsin

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1. INTRODUCTION

THIS research describes an investigation of the automobile and driver visual-motor characteristics by means of closed-circuit television (Brown, 1960; Scott *et al.*, 1963) and real-time computer methods (Ansell and Smith, 1966; Crossman *et al.*, 1966). An attempt was made to apply systems concepts to an understanding of the automobile and its driver as a specialized control system wherein the car is viewed as a rigid wheeled exoskeleton of the driver's body. The design of an automobile should consider the compliant vision, dynamic motion, and the control and response characteristics of the driver. In visual and motor control, the driver is believed to guide the car by using points on the hood or front of the car as cursors in tracking relative space displacement between the dynamic movements of steering and the visual operational effects of these movements.

The background of this research lies in three sectors of prior investigation—i.e., the effects of displaced vision on performance and learning, the human factors analysis of exoskeleton prototypes of anthropomorphous walking machines and lifting machines, and the development of some computer methods for experimental automation of human performance and learning research.

Results as long ago as the work of Stratton (1897) and Wooster (1923) have disclosed that angular deviation of vision by mirrors and prisms causes severe changes in accuracy of movement and learning. The precise scientific understanding of the effects of angular displacement of vision on motion was achieved only later, however, when cybernetic television methods were developed for variable feedback study of such displacements (Smith, 1961, 1962; Smith and Smith, 1962). The findings of this research were that accuracy of guidance and learning of particular motions is determined by three ranges of angularly deviated or displaced visual feedback. These ranges consist of: (1) an *indifference* range of

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displacement, within which tremor and other receptor-sensitizing movements operate; (2) a *normal* or *guidance* range, in which movements are guided without difficulty and which can be compensated for without significant degrees of learning; and (3) a *breakdown* range which leads to disorganization of guidance of movement and requires learning to compensate to some degree for the effects of the displacement. The fact has been also observed that the degree of disintegration of motion guidance and the extent of learning required in the breakdown range increase as a function of the magnitude of displacement.

Human factors analysis of the behavioral requirements of anthropomorphous walking machines (Mosher, 1965; Smith, 1965) and lifting machines (Smith, 1966) has indicated that principles of space, time, and force feedback compliance apply to determination of efficient performance accuracy, and learning of manguided vehicles. The findings of this research on large anthropomorphous machines can be applied specifically to analysis of design and performance of the automobile and to procedures of driver testing and training (Kao, 1969a). The first step in such application is to view the automobile not just as another tool but as an exoskeletal control system in which the driver is both a directing and feedback dependent part of the vehicular men–machine interface.

2. DRIVING WITH DISPLACED TELEVISION IMAGES OF ROAD-VEHICLE INTERACTIONS

2.1. *Method*

In order to test the important role of the various sectors of the car hood in information processing for vehicle guidance, a closed-circuit television system was used for the study of the effects of lateral displaced vision in driving (Kao and Smith, 1969). The arrangements of this system are illustrated in Fig. 1. An Ampex 25 mm Vidicon T.V. camera with a horizontal visual angle of 28° and a vertical visual angle of 21° was mounted on top of a 1967 Chevrolet station wagon, near the front. The windshield was covered except for the monitor display placed on the hood immediately in front of the driver. The driver could view the T.V. display much as he observed the road through the windshield, except that the monitor gave a reduced image of the normal road course. The T.V. camera provided a clear image of the road for approximately 75 ft in front.

This camera-monitor link was designed to view the road as a cyclopean eye of the machine exoskeleton. The image, as conveyed to the driver on the monitor, gave the driver an experimentally manipulable, substitute feedback view of the effects of his steering, braking, and accelerating actions. With this system, spatial and temporal properties of the visual feedback of car reactions under control could be varied in a number of specific ways. That is, the displacement of visual feedback could be varied by shifting the locus of the television camera on the car or by changing its viewing direction. The size of the visual field of the road could be controlled (Gordon, 1966) and vision of the parts of the road and front of the car needed for accurate steering isolated and analyzed (Kao and Nagamachi, 1969; Sheridan, 1966). In addition, the effects of viewing varying extents of the road on accurate steering at different speeds could be determined by adjusting the length of the road displayed on the T.V. monitor. The present study was conducted to determine whether different locations of a substitute television eye above the driver's head would result in different levels of steering accuracy in actual driving (Fig. 1). The left and right extremes and center position were selected. The hypothesis tested in the experiment was that the optimal viewing point on a lateral level of the vehicle for the driver would not correspond to driver's eye position but, as in the case of human vision, would be at some point near the midline of the operating system.

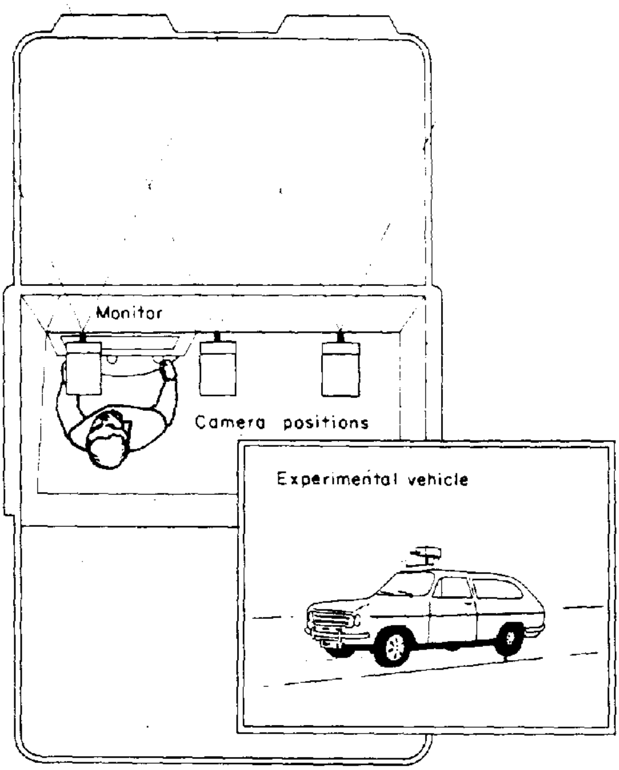

FIG. 1. Experimental arrangement of the three visual conditions by the use of a closed-circuit television system. Also shown is the testing process.

Twelve subjects were tested with three lateral displacements of the T.V. camera with a coverage corresponding to the left, right, and center halves of the car hood. A Latin square design was used to assign the order of treatment to subjects for six combinations of the three camera positions. This was repeated once for the total of 12 subjects. The subjects were licensed staff members and students. Each was run for five trials in a curved road course of 255 ft marked with traffic cones at intervals of 10 ft. The width of the course was 8 ft. With the speed set at 15 mph, each experimental trial was preceded by four trials of practice on a straight course.

2.2. *Results*

The results of steering performance under three visual displacements are summarized in Fig. 2. Statistical difference was found for the three camera positions, $F(2.22) = 6{\cdot}6$, $p = 0{\cdot}01$ with the center position of visual displacement producing the least steering errors. Results of Duncan Range Tests (Duncan, 1965) at the 5 per cent level of significance show that the center image was significantly different from the right but not significantly different from the left position. At the 1 per cent level, only the left and right positions were found to be significantly different.

The overall standard error of the mean was 2·03, showing a rather large variability of performance errors.

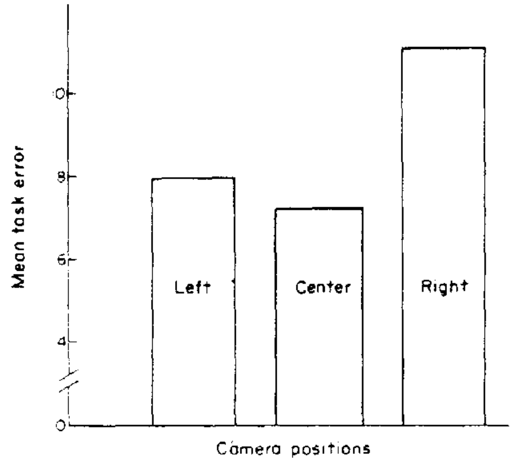

FIG. 2. Bar graph showing the differences in left, center and right camera positions in the driving performance.

2.3. *Discussion*

These results support the general concept that the car operates as an exoskeleton of the driver, who steers on the basis of the effective vision from the car as a wheeled slave skeleton of his own body (Kao, 1969b). The findings indicate that locus of vision in the center of the car on a lateral dimension, as in the case of human body itself, may represent an optimal basis of exoskeleton viewing in vehicle guidance.

The effects of displaced vision on steering accuracy are accounted for theoretically by the general concepts of psychophysiological effects of critical limited ranges of displaced vision. Results suggest that the center and left portions of the car hood as produced from the two corresponding camera positions represent a relatively normal range of vision for efficient driving which may be compensated for by relatively limited driver training, whereas the right image of the car front, generated by right camera position represents displacement within a breakdown range that may require more extensive training to compensate for the effects of the visual distortion.

3. LABORATORY COMPUTER SIMULATION OF STEERING-TRACKING PERFORMANCE

3.1. *Method*

The second phase of this driver research consisted of application of a computer system as a device for both measuring analog records and steering accuracy, as obtained with the videotape recorder, and varying the feedback control parameters in real-time research on steering performance. One feature of the instrumental design used was the integration of the videotape system as an analog recorder of car actions and driver performance with the hybrid computer system for control of visual feedback information in steering. In this case, the videotape recorder was used to generate a dynamic image of the vehicle movement along a road which was viewed by the subject in a simulated display. The subject viewed a monitor image of this display and attempted to control a cursor in relation to variations of the lateral position of the road on the display (Fig. 3).

To achieve the simulated road display, a record was made of a road from a moving car traveling at selected speeds. This record was displayed on a television monitor located near the tape recorder. A television camera viewed this monitor picture through a front surface mirror mounted on a limiting motor. The image from this laboratory camera was displayed on the monitor used as the simulated road display.

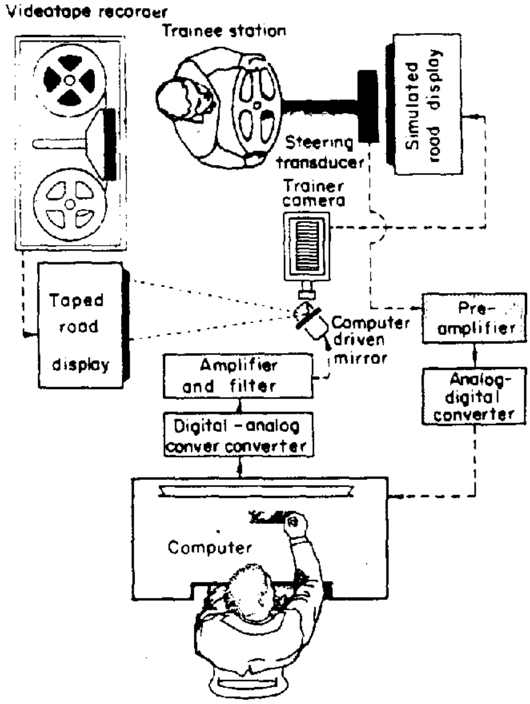

FIG. 3. Cybernetic television and laboratory computer system for the variable feedback research on driver behavior, task simulation and visual manual skill training.

The purpose of the mirror on the limiting motor was to link optically the hybrid computer system and the videotape-generated moving road display. This motor was actuated by an amplifier linked to the digital-analog converter of the computer system, which was programmed to cause the limiting motor to oscillate slowly in a random sine-wave pattern in order to vary the road image back and forth on the simulated T.V. display to the subject.

The computer was used to sense the position of the road display as its variations could be controlled by the steering wheel. Steering motions could compensate for the computer-generated movements of the vehicle display. This action was achieved through programming of proper analog and digital conversion procedures. Steering accuracy was measured by programming the computer to establish a marked center line of the road display as a zero value and to measure deviations from this position as a compensatory error in controlling the movements of the passing road image. This is, the subject's task consisted of keeping the moving road display centered on a cursor point as the display was caused to move laterally back and forth by the program. Figure 4 illustrates the programming of the computer system to automate different aspects of experimental control and measurement in this driving simulation. The various phases of the real-time experimentation are indicated in terms of an oscillograph record of some of the main operations.

Another aspect of the laboratory simulation was to introduce systematic feedback variations in steering and automatically measure their effects on performance. The use of such systematic variations has its origin in the discovery of the detrimental effects of visual lags on tracking performance in the flexible gunnery system mechanisms during the World War II. A main design consideration in this simulation of feedback delay was computer control of the limiting motor and a front surface mirror that linked both the steering wheel and the road display. A program was prepared to delay the effects of feedback output voltage on the action of the mirror and the road display.

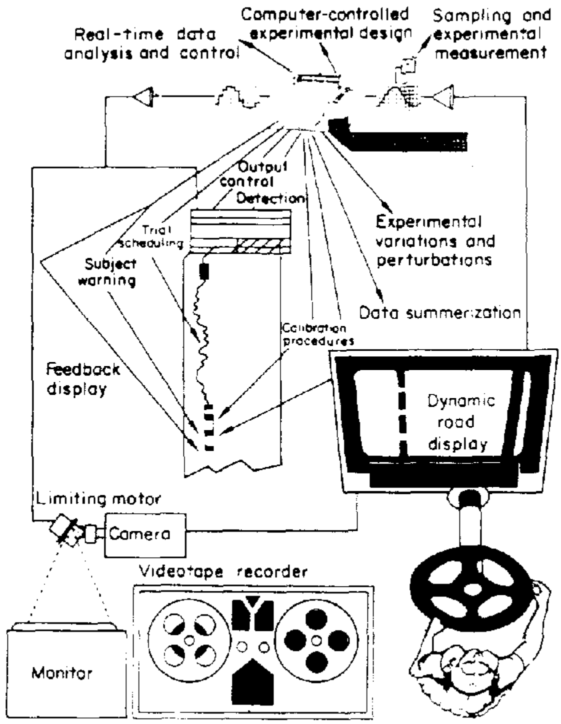

FIG. 4. Parameters of experimental automation in using the hybrid computer-videotape system for both task simulation and visual display.

3.2. *Results*

The series of oscillograph records to the left in Fig. 5 illustrates steering error in two series of five consecutive 1-min trials in the laboratory driving task. The top series of trials represents driving in a rapidly changing or high-speed driving course of 12·9 cycles of change per minute, while the bottom series represents driving in a slowly changing or lowspeed road course of 5·54 cycles per minute. The blocked records below each series of trials record the simulated road course. By comparing the top series of error records with the bottom series, an indication can be obtained of the effects of driving with slow speeds or on slowly curving roads and with high speeds or rapidly changing roads.

The records in the middle of the figure represent the actual tracking movements of the steering wheel in the experiment. The movement patterns resemble those of the driving course used, both slow and fast. The two series of graphic records generally indicate that the smoothness and stability of steering was better with slow than fast course speed. The record to the far right represents the velocity of steering movements; the greater the

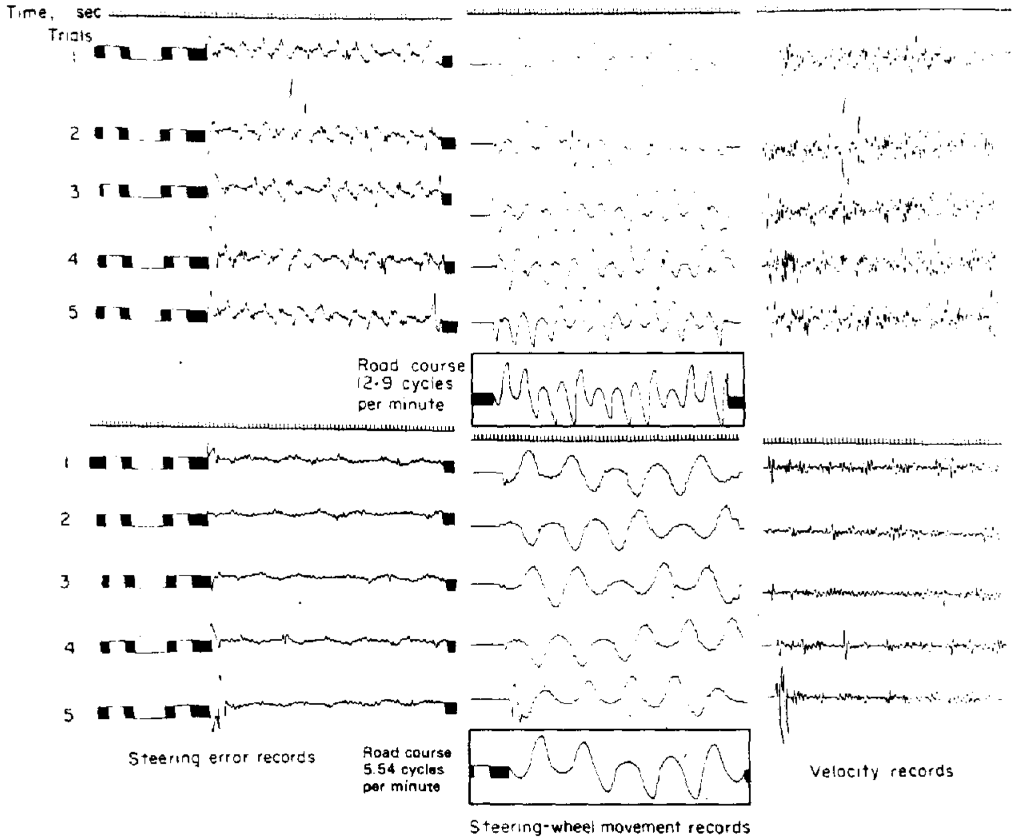

FIG. 5. Oscillograph records of driving error (left), steering movements (middle), and velocity of steering (right). Each record represents a 1-min trial. If the driver had performed perfectly in each trial, the records of steering errors would have been straight lines. The blocked records represent the simulated road courses of different speeds.

variation in the records, the faster the steering wheel was moved. They show that the high-speed course produced relatively far more rapid steering movements than the slower course, and that the relative differences in the rates of the two steering patterns exceeded the difference between the two speeds.

3.3. *Discussion*

The results of this simulation study bring out the point that the actual errors in steering increase with increased speed and rapidly changing road patterns. In actual driving situations, the potential steering error may increase as a direct function of increased speed and changing road patterns. The absence of motion simulation in this study makes this point rather uncertain. Relatively limited improvement in steering performance was observed with the five practice trials for each course. The variations in steering with practice may actually be very limited in many individuals.

The effects on steering of delayed visual feedback from vehicle–road interactions as produced by the computer system simulated the visual lag effects on the driving actions of a car in responding to actual steering of the driver. In the ordinary car or truck, these delayed effects of driver movements are produced by the inertia and related lag of the car response to steering and the degree of friction with the road, and by artificial transmission lags introduced into the steering and braking mechanisms by power systems. Preliminary observations on the effects of delay in the present steering tracking simulation indicate that without motion simulation, visual feedback delays exceeding 0·1 sec could impair steering accuracy and change the characteristics of steering movements, as far as visual–manual control mechanisms are concerned.

4. POTENTIAL APPLICATION OF A VIDEOTAPE SYSTEM IN LABORATORY SIMULATION STUDY

Results of the two phases of research described in this report have indicated the feasibility of using the videotape recorder as a means of registering steering accuracy on the road and of automating measurement and assessment of such analog records with the laboratory computer system. The setup now under development for quantifying tape records of road performance is indicated in Fig. 6. The tape record of performance of a

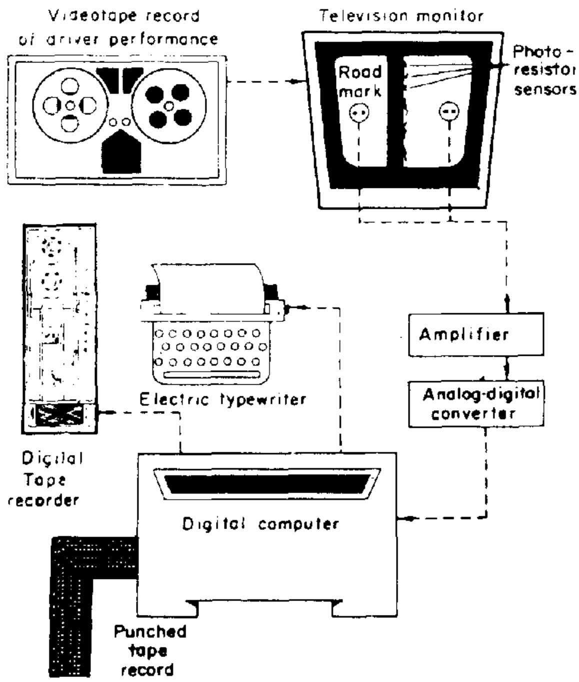

FIG. 6. The use of a videotape machine as an analog recorder of driver steering accuracy and that of a hybrid computer system for automatic measurement of the videotape records.

road marker, as taken from the side of a moving car, is replaced by a videotape recorder and displayed on a monitor. Photoresistor sensors mounted in front of the monitor sense variations in position of the displayed road marker. The transduced analog error signal from the photoresistors is amplified and converted to digital form and then analyzed and reduced by the hybrid computer methods. This system is being developed and refined. Experimental research is planned in this direction.

5. CONCLUSIONS

1. In an experimental systems concept, the automobile is viewed as a rigid, wheeled exoskeleton of the driver. It possesses certain perceptual characteristics for effective vehicle guidance. These are partially determined by the locus of vision on the machine skeleton.

2. Both closed-circuit television and computer methods have been developed to test experimental systems assumptions that space and time compliance between car action and driver control behavior and perception affect steering accuracy and driver characteristics.

3. The systems methods for measuring feedback factors in steering consist of television system methods to control vision of the car in relation to the road, videotape techniques for generating moving road displays in simulated driving situations, and a hybrid computer system for controlling feedback display and steering accuracy in simulated driving.

4. Using the cybernetic television methods, the results of the first study showed that different lateral displacements of vision would affect drivers' steering accuracy. Preliminary results indicated that a center locus of vision in the car exoskeleton may represent an optimal condition of displaced vision for vehicle control.

5. The findings from the laboratory simulation of driver steering task have implications in visual-motor skill learning and training.

6. Results from the T.V. driving study call for some design considerations in the perceptual aspects of vehicle front end configurations for improved vehicle–road tracking.

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